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Continuous temporal soil-gas composition variations for earthquake precursory studies along Hsincheng and Hsinhua faults in Taiwan

Vivek Walia[a,*], S.J. Lin[a], W.L. Hong[b], C.C. Fu[b], T.F. Yang[b], K.L. Wen[a,c], C.-H. Chen[b]

[a] National Center for Research on Earthquake Engineering, National Applied Research Laboratories, Taipei 106, Taiwan
[b] Department of Geosciences, National Taiwan University, Taipei 106, Taiwan
[c] Department of Earth Sciences and Institute of Geophysics, National Central University, Jhongli 32054, Taiwan

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ABSTRACT

Measurement of soil-gas emissions along active zones is demonstrated as a geochemical tool to identify and monitor tectonic activity in the region. The present study is proposed to investigate geochemical variations of soil-gas composition in the vicinity of geologic fault zones of Hsincheng Fault and the Hsinhua Fault within the Hsinchu and Tainan areas, respectively, and to determine the influence of such formations on enhanced concentrations of different gases in soil to monitor the tectonic activity in the region. To carry out the present investigation temporal variation in soil-gases compositions was measured at continuous earthquake monitoring station established along the above said faults. Observations have shown potential precursory signals for some major earthquakes in the region. Results have shown that Hsinhua and Hsincheng Faults have different tectonic settings. Hsinhua soil-gas variations show precursory signals for earthquakes occurring in south or south eastern part of Taiwan, whereas, for Hsincheng Fault most of soil-gas variation precursory signals were recorded for the earthquakes that occurred along Okinawa Trough and Ryukyu Trough.

1. Introduction

The island of Taiwan is a product of the collision between Philippine Sea plate and Eurasian plate which make it a region of high seismicity. Active subduction zones occur south and east of Taiwan. To the south an oceanic part of the Eurasian plate is subducting beneath the Philippine Sea plate along the Manila Trench, whereas in east the oceanic lithosphere of the Philippine Sea plate is subducting northwestward underneath Eurasian plate along Ryukyu Trench (Fig. 1a). These collisions are generally considered to be the main source of tectonic stress in the region.

Looking at the tectonic map of Taiwan, one can find about 42 identified active faults (Fig. 1b). The present work is focused on Hsincheng Fault in Hsinchu area and the Hsinhua Fault in Tainan for earthquake monitoring using soil-gas method (Fig. 1). It is well established that distribution of soil-gas compositional variations can be employed as the precursors for earthquakes (Segovia et al., 1989; Woith and Pekdeger, 1992; Walia et al., 2005b; 2006; Yang et al., 2005, 2006; Fu et al., 2008) and for mapping of fault zones (Al-Taminmi and Abumurad, 2001; Guerra and Lombardi, 2001; Fu et al., 2005, 2009; Walia et al., 2005a). Studies on diffuse degassing from subsurface carried out have clearly shown that gases can escape towards the surface by diffusion and by advection and dispersion as they are transported by rising hot fluids and migrate along preferential pathways such as fractures and faults (King et al., 1993; Baubron et al., 2001; Yang et al., 2003). To explain radon migration over large distances, several models have been elaborated and it has been established that radon is transported by underground water or carrier gases, such as CO_2, CH_4, He or N_2 (Kristiansson and Malmqvist, 1982; Etiope and Martinelli, 2002). Its rate of migration and its soil-gas concentration are controlled by a large number of factors such as the distribution of uranium in the soil and bed rock, soil porosity and humidity, microcracks, granulation, surface wind etc.

Faults can be described as weakened zones composed of highly fractured materials, gouge and fluids. Active faults favor gas leaks because they usually increase the permeability of soils. The Hsincheng active fault is located in/near the Hsinchu National Science Industrial Park (HNSIP) in northern Taiwan and has been defined as a low angle thrust fault by seismic profiling. Based on trench observation and paleoseismic study in this area, the slip rate of Hsincheng Fault is about 0.7–1.6 mm/yr; the recurrence interval is about 2 ka; and the latest slip record was ca. 300 years ago. In this regard, the Hsincheng Fault has been classified as an

* Corresponding author. Tel.: +886 2 6630 0575; fax: +886 2 6630 0858.
E-mail addresses: vivekwalia@rediffmail.com, walia@ncree.org.tw (V. Walia).

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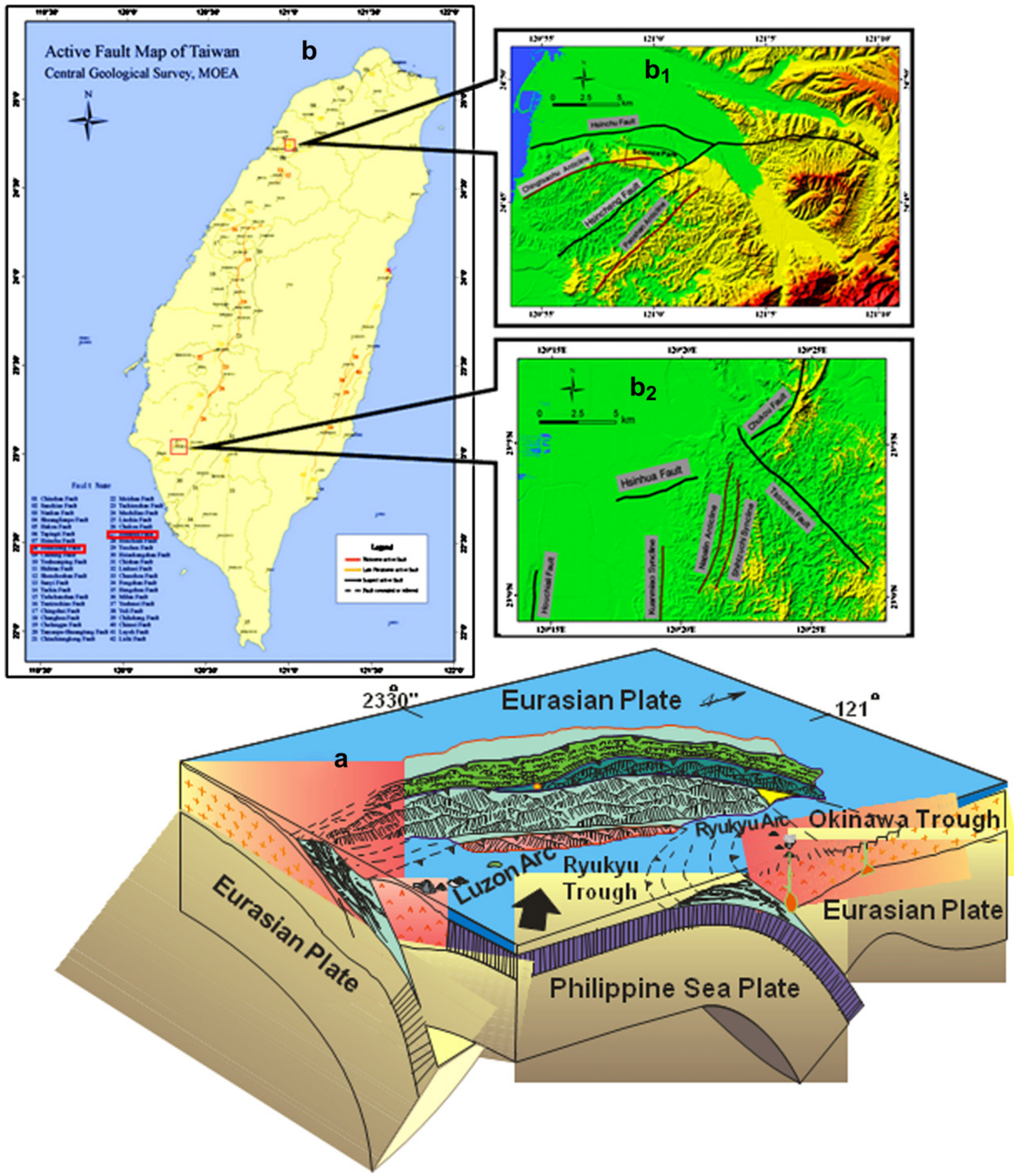

Fig. 1. (a) 3D tectonic model of Taiwan, (b) Active fault map of Taiwan along with tectonic setting of monitoring stations locations: (b_1) Hsincheng Fault (b_2) Hsinhua Fault.

active fault with northeast trends by Central Geological Survey, MOEA (Lin et al., 2000). There are some other northeast–southwest faults and anticline systems in this area: Hsinchu Fault, Paoshan Anticline and Chingtsauhu Anticline (Fig. 1b_1). Numerous outcrops on the Hsincheng Fault have been documented that describe the style of faulting (Hsu and Chang, 1979). The major formations present in the area are: Yangmei Formation (sandstone–shale alternations predominant with sandstone), Cholan Formation (siltstone–sandstone alternations predominant with sandstone), Toukoshan Formation (sandstone–shale alternations and sandstone), laterite terrace (gravel, sandstone and siltstone predominant with laterite) and alluvium (uncemented sand, mud, gravels and pebbles).

The Hsinhua Fault is recognized as one of the active faults in southwestern Taiwan. It was considered to be right-lateral slip fault and the last movement on it occurred in 1946 accompanied by an earthquake ($M = 6.3$) (Hsu and Chang, 1979; Chang et al., 1947). But later studies of Lee et al. (2000) using seismic data identified it as a back-thrust fault dipping north 17° at great depth and at a high angle 70° near surface. It is located in the coastal plain and foothills

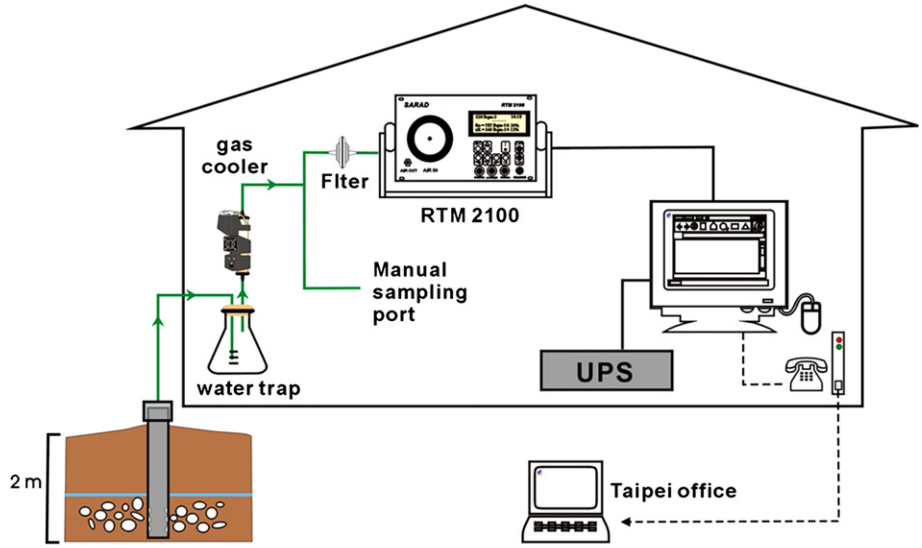

Fig. 2. Sketch scheme for continuous earthquake monitoring station.

in the southwestern part of Taiwan about 10 km northeast of Tainan City. Some studies have shown that this fault is not only the 1946's earthquake fault but also a fault that has moved many times in the past (Hsu and Chang, 1979; Hwang et al., 2003). The total length of the fault in the subsurface probably was 12 km or more. Judging from its location, orientation and sense of slip, this structure is also likely to be an accommodation structure in the transition zone (Lee et al., 2000). Presence of some major tectonic elements including

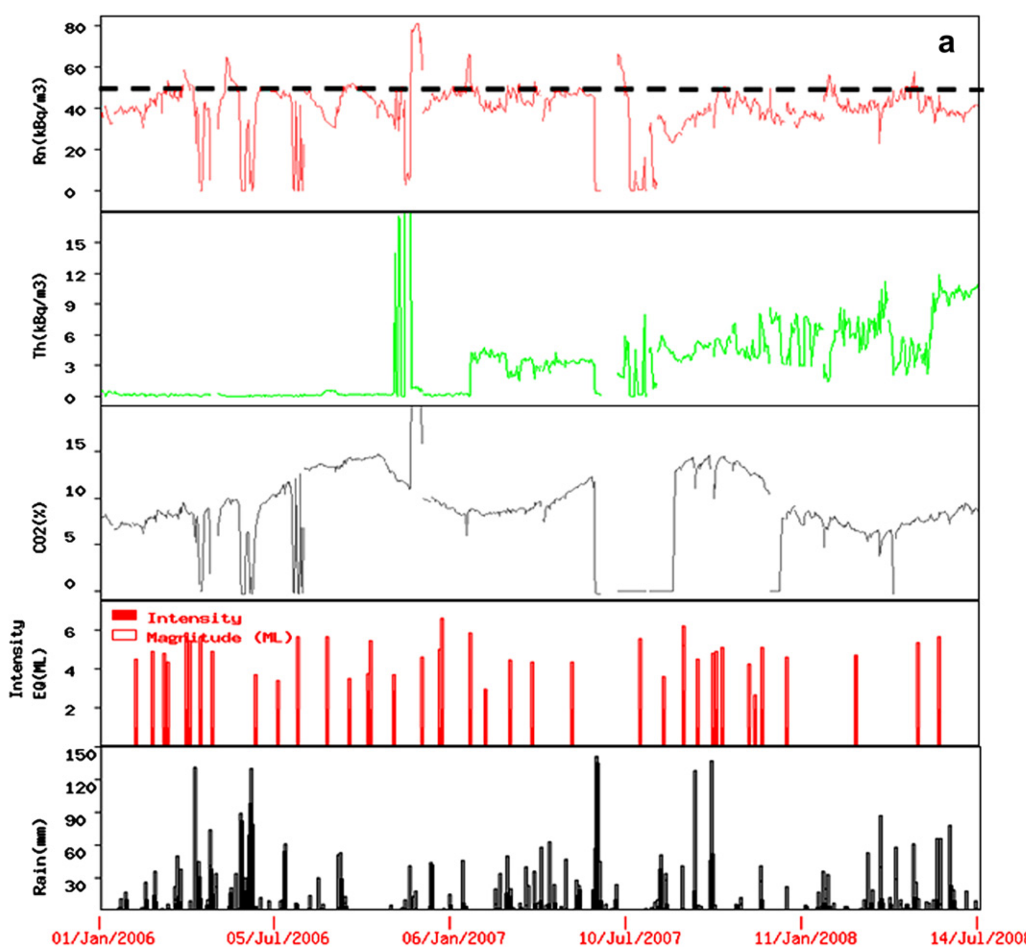

Fig. 3. Daily variations of radon (with dashed line as threshold value for identifying the anomalies), thoron, and rainfall at (a) Hsincheng Fault, (b) Hsinhua Fault, monitoring stations and its correlation with earthquakes. (c) Variations of radon, carbon-dioxide and rainfall at Hsinhua monitoring station and its correlation with twin earthquakes of Dec. 26th 2006.

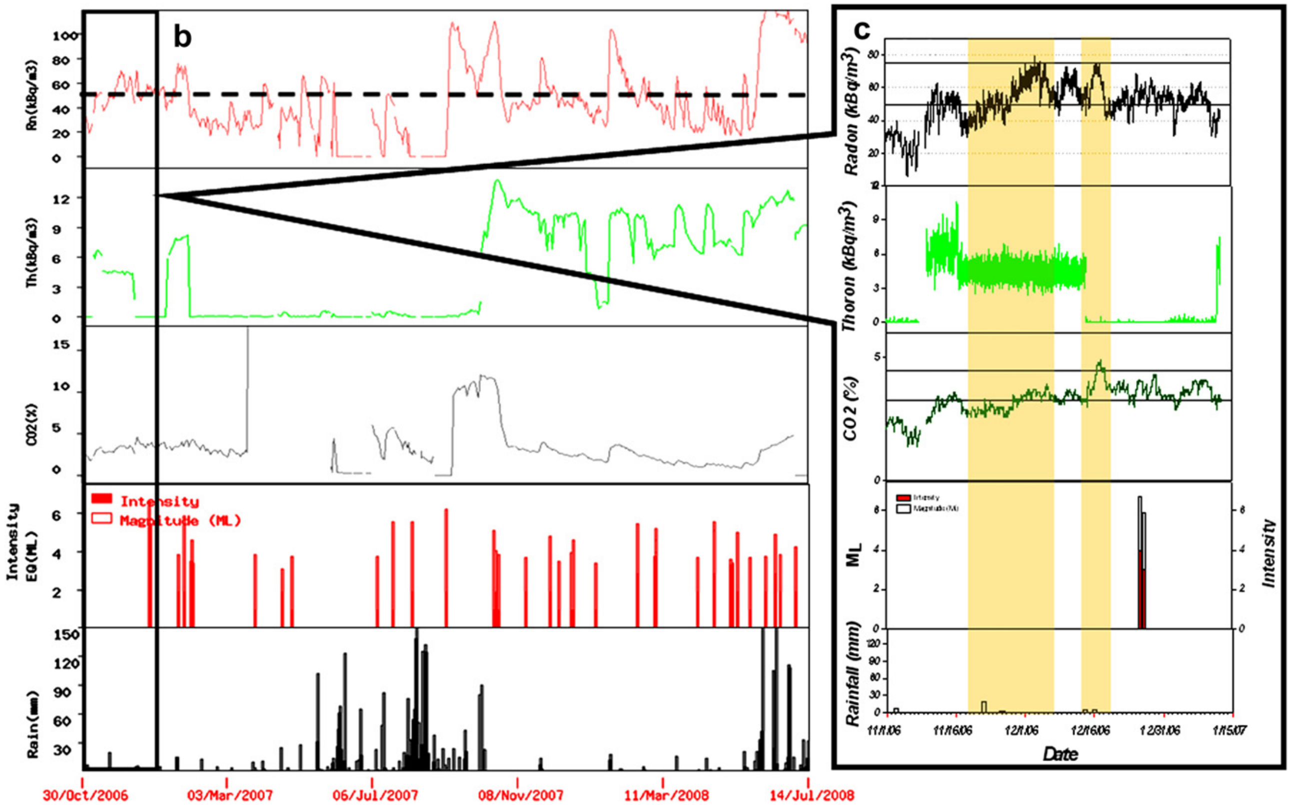

Fig. 3. (*continued*).

Chukou Fault, Tsochen Fault, Napalin Anticline, Shihtzuchi Syncline in the foothills belt and Kuanmiao Syncline, Houchiali Fault in the Tainan basin around the studied Hsinhua fault are the part of fold-and-thrust belt that formed during the Penglai Orogeny (Fig. 1b$_2$). The major formation in the area is Liushuang Formation besides terrace and alluvium. Upper part of Liushuang Formation is predominantly composed of brown-yellowish sandstone while the lower part is thick mudstone. Terrace and alluvium comprises mainly uncemented sand, mud, gravels and pebbles.

In the present study we have focused on temporal geochemical variations of soil-gas composition at established geochemical observatories along the Hsincheng and the Hsinhua faults in Hsinchu and Tainan areas of Taiwan, respectively and to determine the influence of enhanced concentrations of soil-gases to monitor the tectonic activity in the region. Both the above said faults are located on/near National Science Industrial Park (NSIP), the industrial hub of Taiwan, and can be cause of concern making it necessary to check the activity to these faults.

2. The monitoring station

In the earlier phase of the work reported elsewhere (Walia et al., 2009) focus was on finding the fault location of Hsincheng and Hsinhua faults and on the site selection criteria to build continuous monitoring station. Based on these studies, selected sites were tested for continuous monitoring. All the sites were observed by digging holes of 2 m and by casing these holes with PVC pipes. At the bottom of PVC pipe a fine mesh is attached to avoid any unwanted materials to enter the pipe. The PVC sheet is put on all the sides of the PVC pipe at bottom and cemented at the surface with drainage covering about 1 m on all sides, this is done to avoid the rain water to get into the hole. In addition some pebbles are also placed at the bottom before filling the sides of the holes. All this is done to reduce the meteorological effects. Later the most sensitive site was selected (Walia et al., 2009) for final setup of monitoring station and housing was done on it. Long term continuous earthquake monitoring was started along both the said faults after following said criteria.

Fig. 2 shows the sketch of the established automated monitoring system. After passing through the water trap and gas cooler, the soil-gas is transferred into an alpha spectroscopy (SARAD-RTM2100) via an internal pump for radon and thoron measurement and having additional carbon-dioxide detector (Fig. 2) with sampling interval of 15 min. All the data could be transferred to Taipei office via the internet for further analysis. Data for rainfall and seismic parameters (viz. earthquake

Table 1
Statistical analysis of recorded data at both the monitoring stations.

Station name	Total anomalies (a)	Total seismic events (b)	Anomalies related with events (c)	Anomalies not related with seismic events (d)	Signal (%) (c/a)	Noise (%) (d/a)	Confidence level (signal/noise)
Hsincheng fault	29	38	18	9	62	38	1.63
Hsinhua fault	28	28	22	6	79	21	3.76

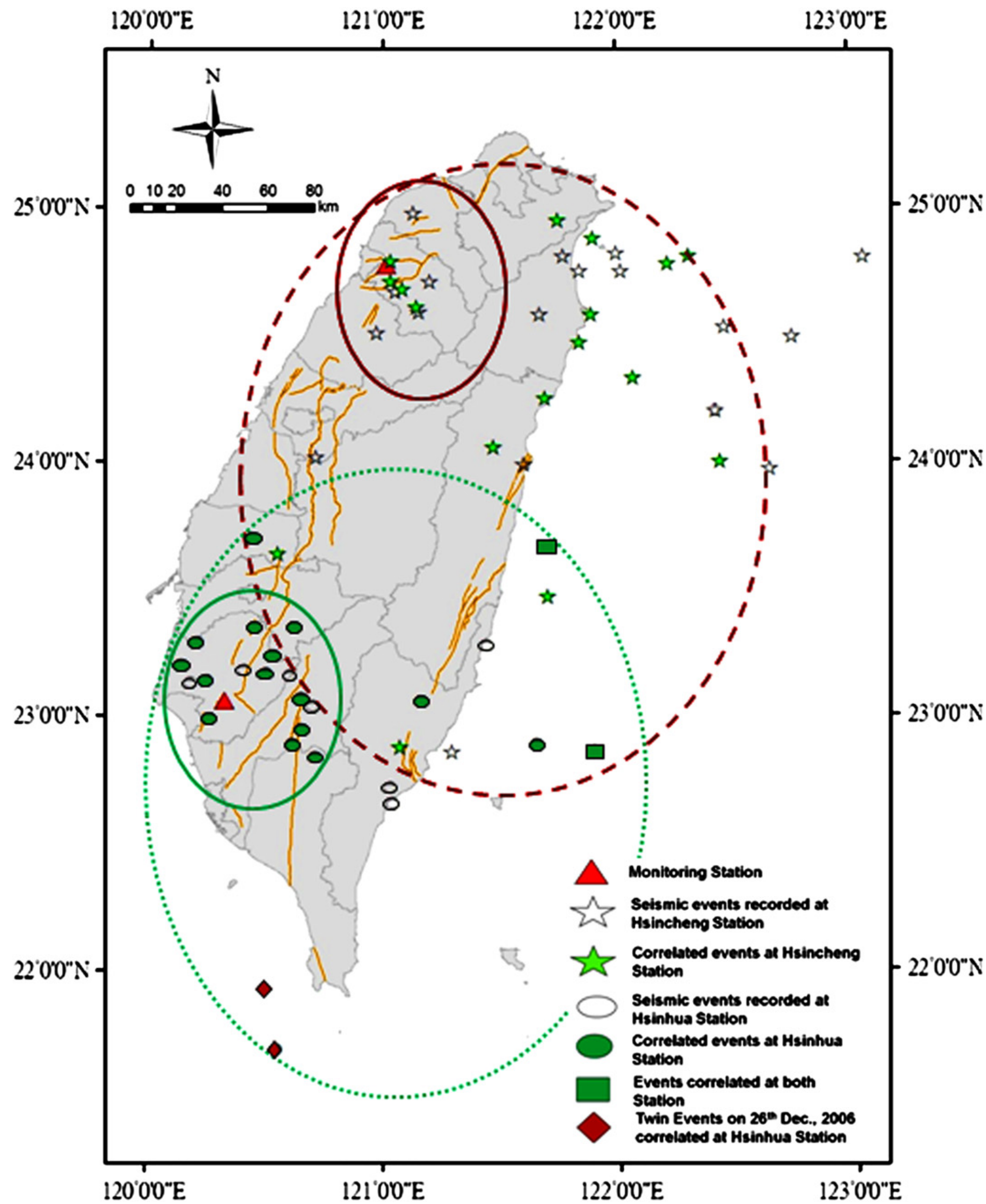

Fig. 4. Distribution of events recorded at monitoring stations along Hsincheng and Hsinchua faults.

parameters, intensity at monitoring station etc.) were taken from Central Weather Bureau of Taiwan (www.cwb.gov.tw). Continuous monitoring was started in January, 2006 and November, 2006 along Hsincheng and Hsinhua faults, respectively.

3. Results and discussions

Investigations during the observation period at the monitoring stations have shown potential precursory signals for some major earthquakes in the region. During the observation we have found that in some cases number of earthquakes happened in short span of time i.e. within 1–5 days, these earthquakes can be aftershocks/foreshocks of big earthquakes or different earthquakes. In the present study we have considered these as one seismic event.

3.1. Hsincheng Fault

Long term geochemical monitoring for the earthquake studies at the established earthquake monitoring station along Hsincheng Fault inside the Hsinchu National Science Industrial Park (HNSIP) (Fig. 2) has been done continuously. During the period of observation (January, 2006 until mid-July 2008), about 38 seismic events were recorded and from which 29 anomalies were observed (anomaly is defined according the procedure followed in the earlier study (Walia et al., 2009)). From these 29 anomalies, 18 anomalies can be correlated with the 18 seismic events (Fig. 3a). Most of non-correlated events are either having no soil-gas data (due to instrumentation problems or the events occurring during heavy rainy seasons) or deep focused events. During heavy rains, water percolated down and affected the gas emanation thus prevented gas to migrate towards the surface. For the above-mentioned period of observation, about 62% of anomalies can be correlated with seismic events in the region and the rest of anomalies may have occurred due to ongoing crustal deformation in the region which is not mature enough to produce an earthquake.

3.2. Hsinhua Fault

Geochemical monitoring for the earthquake studies at the established earthquake monitoring station along Hsinhua Fault in Tainan area has also been done continuously during the period of observation (i.e. Nov, 2006 to mid-July, 2008). In this period, potential precursory signals were recorded for some earthquakes that occurred in the region (Fig. 3b). About 28 seismic events were recorded and same numbers of anomalies were also recorded at the monitoring station. From this, 22 can be correlated with the same number of seismic events. All of non-correlated events occurred during heavy rainy season and thus no anomalies can be detected for these events. This monitoring station has shown better confidence level and less noise than monitoring station along the Hsincheng Fault, hence seems to be a better station (Table 1).

Soil-gas variations at Hsinhua monitoring station have shown good correlation with impending off shore twin earthquakes of 26th December, 2006 both having magnitude of 7 with local intensity of 4 (Fig. 3c), considered as the biggest earthquake in the region (south of Taiwan (Fig. 4)) in last few years. The radon concentration shows variation around 40 kBq/m^3 with deviation of about 15 kBq/m^3 in the normal conditions. Radon concentration shows steady increase after 21st of November, 2006 and reaches to its maxima of about 80 kBq/m^3 on 3rd December, 2006 more than 2σ values for the observation period (shown by horizontal solid line in Fig. 3c), followed by decrease to its normal values of about 50 kBq/m^3. These trends of increase and reaching to normal values continue till final anomaly on 16–17 Dec., about 10 days before the earthquake. The CO_2 carrier gas for the radon in the region also shows anomalous values on 16–17 Dec. (Fig. 3c). Whereas thoron (220Rn), another isotope of radon having very short life of 54.55 s as compared to radon (222Rn), has also shown comparatively higher values from middle November to middle December. These high values of radon, thoron and CO_2 before the earthquake at the monitoring station are the precursory signals of 26th December, 2006 earthquakes which developed due to the building of stress in the region before the main events. But no precursory signals were recorded at Hsincheng monitoring station although these earthquakes shook the whole Taiwan which may indicate that degassing systems at Hsincheng Fault were not disturbed by the stress induced by tectonic system in south oceanic part of Taiwan due to subduction of the Philippine Sea plate along the Manila Trench.

4. Conclusions

The above results indicate that both Hsinhua and Hsincheng faults may have different tectonic settings. Hence, it can be said that soil-gas variations at Hsincheng Fault were disturbed by the stress variation due to tectonic activities along Okinawa Trough and Rkukyu Trough which are located in north and central eastern part of Taiwan, respectively in addition to local earthquakes within periphery of about 50 km from the monitoring station (indicated by solid circle Fig. 4). Whereas in the case of Hsinhua Fault, soil-gas variations were observed to be due to tectonic activities along the Luzon Arc and other tectonic activities in southern part of Taiwan. So, soil-gas variations at Hsinhua monitoring station show precursory signals for earthquakes occurring south or south eastern part of Taiwan (Fig. 4), whereas, for Hsincheng Fault, most of soil-gas variation precursory signals were recorded for the earthquakes that occurred along Okinawa Trough and Rkukyu Trough (Fig. 1a).

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